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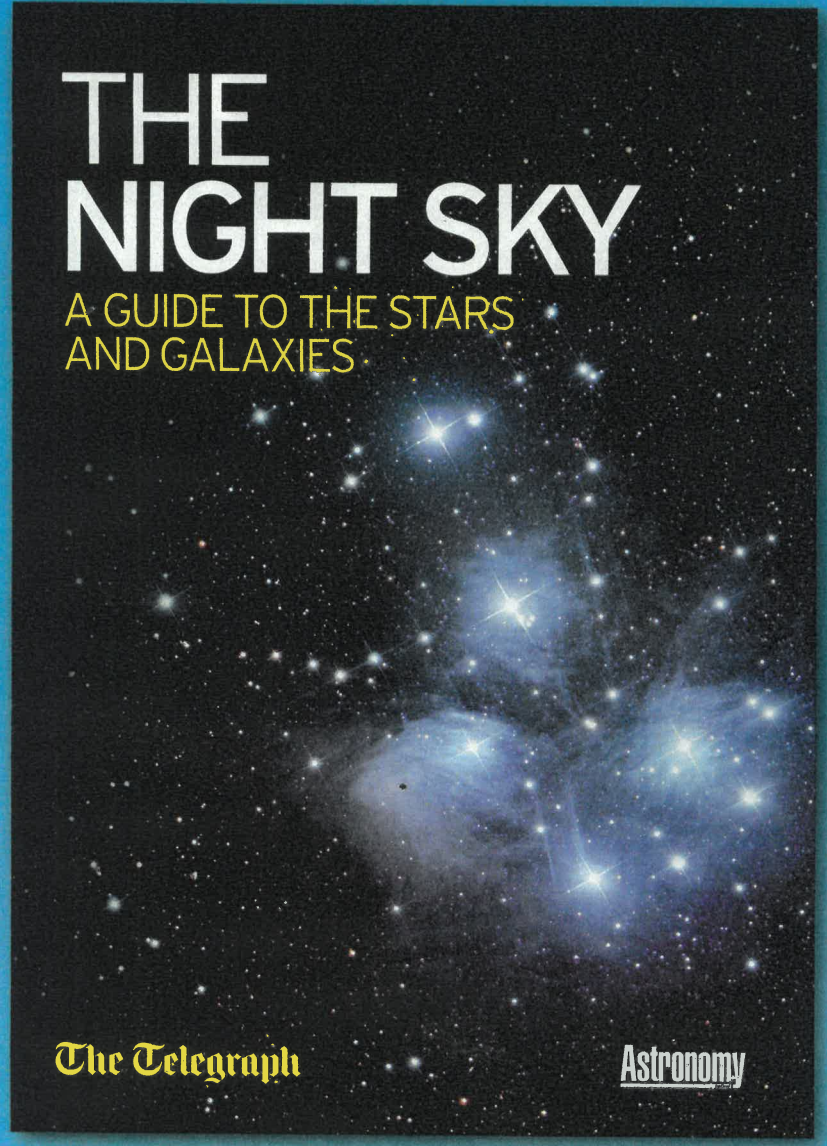
THE NIGHT SKY

A GUIDE TO THE SOLAR SYSTEM

The Telegraph

Astronomy

FREE INSIDE TOMORROW'S SUNDAY TELEGRAPH



Don't miss your 40-page practical stargazing guide

Astronomy is the oldest science in the world and one of the most fascinating. It is also a science in which anyone can play a part, without the need for expensive equipment.

This booklet will take you on a tour of the Solar System, our home in space; our life-giving Sun at its centre, orbited by the eight planets, including our Earth, its companion Moon and a host of minor bodies.

Because the planets are so close on the cosmic scale, even a small telescope is good enough to show you details on some of them. We can see the dark patches on Mars, the cloud belts on Jupiter, and the glorious icy rings of Saturn.

Every planet has its own characteristics, though we must agree that there is no planet except ours where human beings could survive without special protection. Once we reach the limits of our Solar System it will be time to continue our journey into the far reaches of the Universe.

Read on, and let this booklet take you on an enthralling journey through the night sky and the fascinating wonders of our Solar System.

Don't miss *A Guide to the Stars and Galaxies* free inside tomorrow's Sunday Telegraph.

SIR PATRICK MOORE

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OBSERVATION TERMINOLOGY

MAGNITUDE a scale used to measure the brightness of celestial objects - the lower the magnitude, the brighter the object.

OPPOSITION the occasion when a planet, asteroid or comet lies in the opposite direction to the sun, when viewed from Earth.

Our Solar System

ROCK PLANETS
Mercury, Venus, Earth, Mars

GAS PLANETS
Jupiter, Saturn, Uranus, Neptune

ASTEROID BELT (not shown)
Situated between Mars and Jupiter.
Contains the dwarf planet Ceres

The Sun

THE SUN IS THE CENTRE OF THE SOLAR SYSTEM, BUT IS ALSO JUST ONE STAR AMONG HUNDREDS OF BILLIONS IN THE MILKY WAY

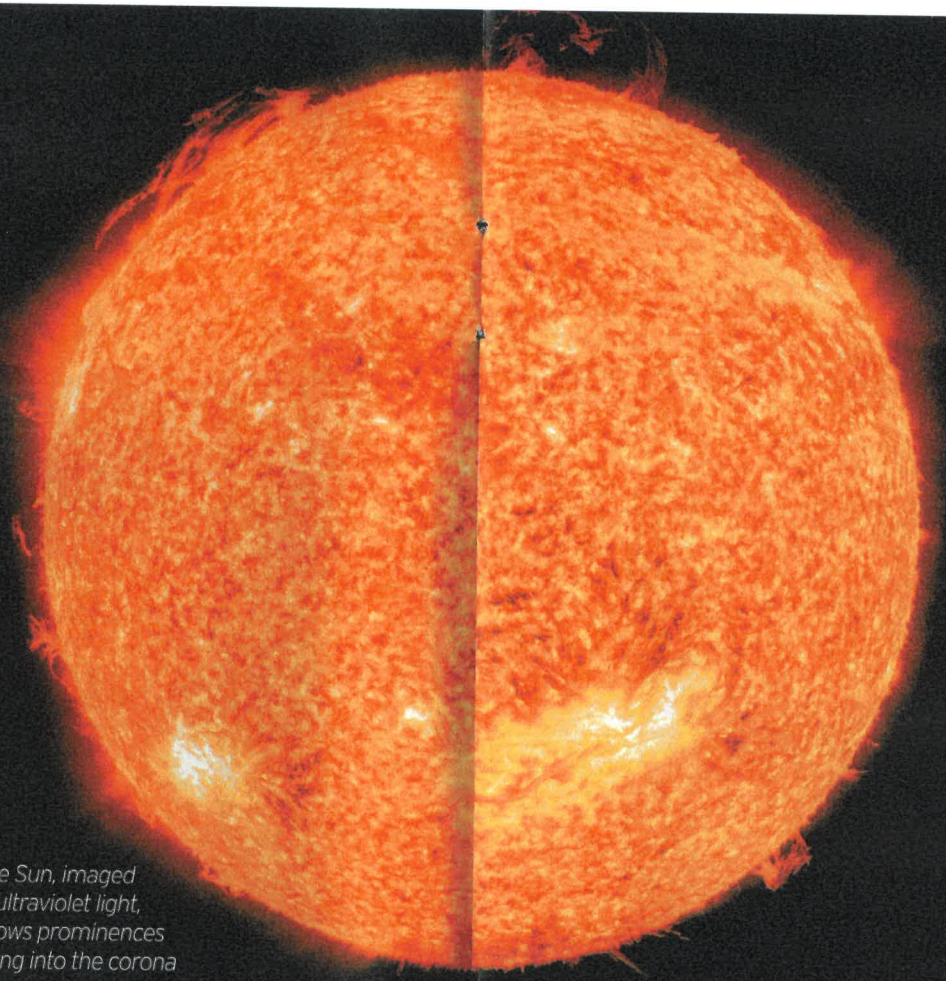
Our closest star is the Sun. Its energy warms our planet, giving us light and life. The Sun lies at the heart of our Solar System, orbited by all the planets, comets and asteroids. A 1.4-million-kilometre gas ball made primarily from hydrogen, the Sun generates energy through nuclear fusion within its core, where temperatures reach 15 million degrees Celsius. Its surface boils and bubbles, often erupting in huge flares, or prominences, that dwarf Earth.

PROMINENCES

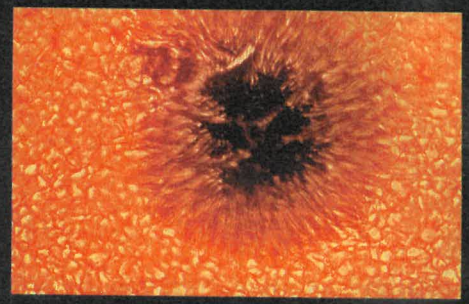
Prominences are ejections of electrified ('ionised') gas called plasma that is suspended along magnetic field lines in a region called the corona, the Sun's million-degree hot outer atmosphere. The patterns seen on the Sun's surface, called the photosphere, are made from roiling gas, 5,500C, that follows magnetic field lines within the photosphere.

MAGNETIC FIELDS

The Sun transports energy from its core via radiation within the inner two thirds of its sphere, and convection within its outer third. A dynamo effect between the radiative and convective zones, which rotate at different speeds, causes the magnetic field on the surface. Think of it as a pan of water simmering on the hob: when those magnetic fields bubble to the top, things can boil over, leading to eruptions on the surface.



› *The Sun, imaged in ultraviolet light, shows prominences rising into the corona*



› *A sunspot, showing black on the Sun's surface*

SUNSPOTS

Sunspots are magnetic disturbances where magnetic field lines that have become knotted rise up into the photosphere. Although still 4,000C, they appear black in contrast to their even hotter surroundings. Sunspots can be gigantic, stretching tens of thousands of kilometres across and they always come in pairs (of opposite polarity) or clusters of pairs.

FACT FILE

CLASSIFICATION star

COMPOSITION 71% hydrogen, 27% helium, 2% other elements

DIAMETER 1.4 million km / 109 times bigger than Earth

DISTANCE FROM EARTH 149.6 million km

LENGTH OF DAY 25 Earth days

SURFACE TEMPERATURE 5,500C

SOLAR STORMS

The largest and most powerful type of solar eruption is known as a coronal mass ejection (CME). It is a solar storm consisting of magnetic bubbles of million-degree hot plasma that explode from the Sun and race across space at velocities of several thousand kilometres per second. Modest CMEs occur on the Sun every day, carrying up to 50 billion tonnes of solar material as they rip themselves out of the corona. The really big CMEs usually occur when activity and magnetic tension is at its peak.

DID YOU KNOW... A solar storm in 1989 created electrical ground currents that tripped Quebec's power grid, plunging the Canadian province into darkness for several hours.

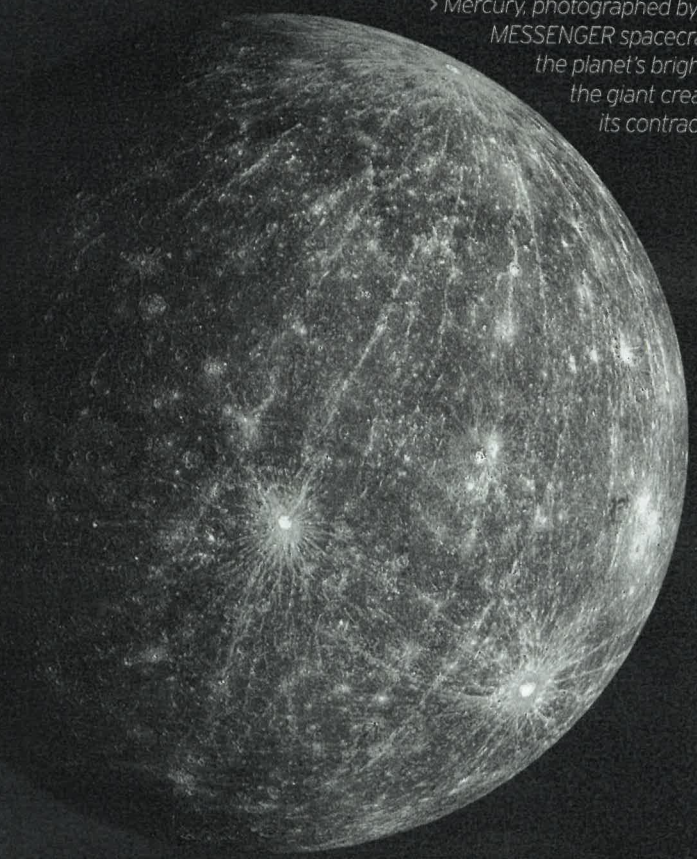
HOW TO OBSERVE

HOW never with the naked eye, binoculars or a telescope without appropriate and specialised solar filters

BRIGHTNESS max magnitude -26.73

WHEN all year, during daylight

BEST SEEN using specialist solar telescopes and filters



› Mercury, photographed by NASA's MESSENGER spacecraft. You can see the planet's bright craters and the giant creases caused by its contraction

Mercury

THE INNERMOST AND SMALLEST PLANET OF OUR SOLAR SYSTEM LOOKS MUCH LIKE OUR OWN MOON AT FIRST GLANCE. BUT APPEARANCES CAN BE DECEPTIVE...

Scarred with craters, cliffs and trenches, plains of frozen lava and hollow volcanic pits, bright spots, dark rays and so-called 'weird terrain', 4,879km-wide Mercury certainly has a complicated tale to tell.

VOLCANIC PAST

Glimpses of gently rolling hilly plains in between craters mark some of Mercury's oldest surface features, however volcanoes have shaped much of the planet's crust. Large smooth plains and occasional valleys, formed by cooled lava several kilometres thick, dominate the landscape. Bright markings around craters with steep-walled pits are also interpreted as volcanic deposits from explosive volcanoes.

FACT FILE

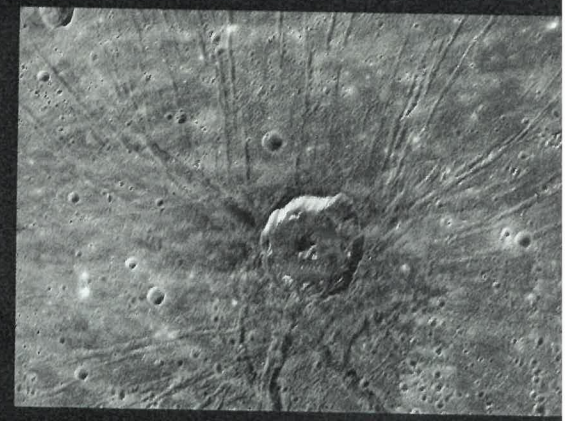
CLASSIFICATION	rock planet
ATMOSPHERE	42% molecular oxygen, 29% sodium, 22% hydrogen, 6% helium, 0.5% potassium, trace amounts of argon, nitrogen, carbon dioxide, water vapour, xenon, krypton, neon
DIAMETER	4,879 km / 0.38 the size of Earth
DISTANCE FROM SUN	57.9 million km
LENGTH OF DAY	58.7 Earth days
SURFACE TEMPERATURE	-193C to 437C
NUMBER OF MOONS	none

WRINKLE RIDGES

For a few hundred million years, Mercury was bombarded by asteroid and comet storms, which carved out the giant basins and craters that can be seen on both Mercury and the Moon today. That storm period ceased 3.9 billion years ago, and since then Mercury has been cooling despite its volcanic activity. So-called wrinkle ridges, formed as Mercury contracted, snake across the planet's surface.

The rotation of Mercury is somewhat strange: it has a very slow spin such that it rotates once on its axis every 58.7 days, which is exactly two-thirds of its orbital period of 88 days. That means it turns on its axis one and a half times during one of its circuits around the Sun, causing the Sun to appear to move backwards relative to the stars for one full turn. As a result, it has only half a day during one year, so that one solar day on Mercury lasts for two Mercury years.

DID YOU KNOW... Mercury's metal-rich core occupies three-quarters of the diameter of the planet – that's about the equivalent size of Earth's Moon.

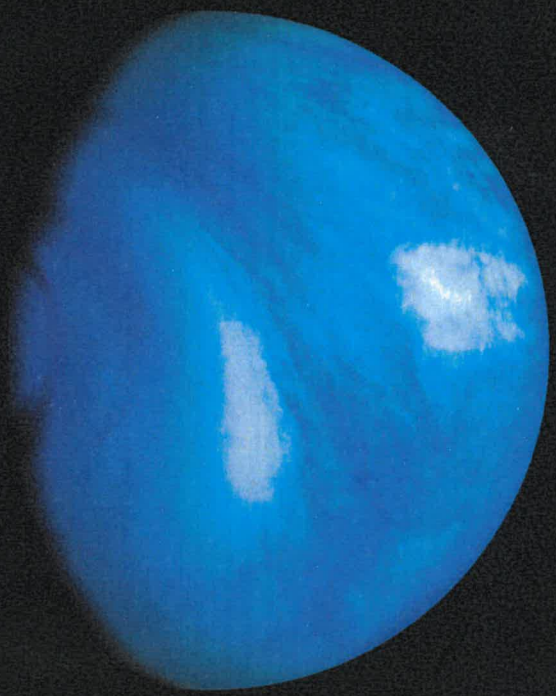


› This 40km wide crater is found at the heart of an even larger impact feature, the 1,550km wide Caloris Basin. The strange spidery pattern is a bit of a mystery and may have formed after magma pushed upwards from underneath Caloris

During this lengthy day temperatures rise from a frigid -193C at night-time to a scolding 437C in the daytime. Yet the floors of numerous deep craters at the poles are never exposed to sunlight, meaning that ice is stable, a finding confirmed by NASA's MESSENGER (MErcury Surface, Space ENvironment, GEochemistry and Ranging) spacecraft.

HOW TO OBSERVE

HOW	naked eye
BRIGHTNESS	max magnitude -2.6
WHEN	visible for six or seven weeks a year
BEST SEEN	low in the twilight sky, before sunrise or after sunset



› *A false-colour view of Venus's southern hemisphere showing the thick sulphur dioxide clouds, as seen by the European Space Agency's Venus Express mission*

Venus

HOT, DRY, WINDY, SUNLESS AND BESET BY LIGHTNING STORMS, VENUS IS OFTEN DESCRIBED AS EARTH'S EVIL TWIN

Venus is everything that life wouldn't want from a planet – it's hot, it's dry, the air is choking, the surface pressures are intense, winds constantly blow at a gale, lightning forks incessantly through the skies and the Sun never, ever comes out.

Unlike Mercury, Earth and Mars, where we can see down to the ground, Venus' surface is obscured by thick cloud. Landing craft sent on reconnaissance missions have plummeted through the poisonous atmosphere only to melt in the intense heat or be crushed by an atmospheric pressure 90-100 times that found at the surface of Earth. Orbiting craft have fared better, managing to send back images that reveal Venus's bleak world.

FACT FILE

CLASSIFICATION	rock planet
ATMOSPHERE	96.5% carbon dioxide, 3.5% nitrogen, less than 0.01% sulphur dioxide, argon, water vapour, carbon monoxide, helium, neon
DIAMETER	12,104km / 0.94 the size of Earth
DISTANCE FROM SUN	108.2 million km
LENGTH OF DAY	243 Earth days
SURFACE TEMPERATURE	450C
NUMBER OF MOONS	none

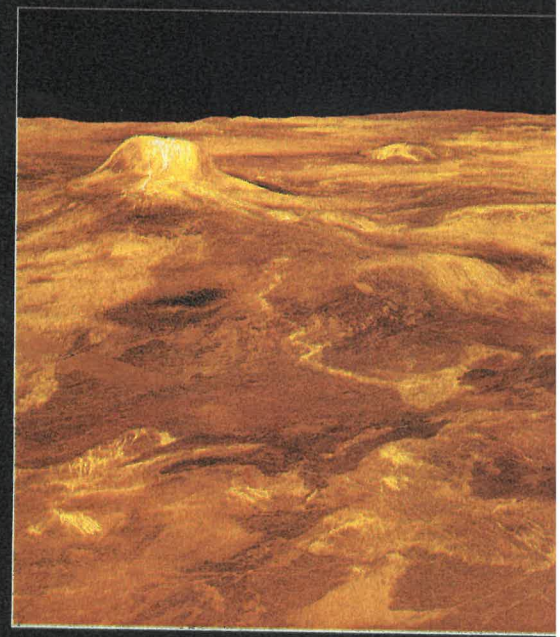
A SHORT HISTORY

Once upon a time, Venus probably had some water, with oceans' worth hanging as vapour in misty clouds. The surface would have been molten, steaming from the heat of its formation and the barrage of impacts as asteroids continued to rain down.

As the Sun grew older, it became hotter and brighter. For Earth this was good news, eventually allowing temperatures suitable for life to be maintained. For Venus, which is 41 million kilometres closer to the Sun, this was bad news. Carbon dioxide built up in the atmosphere, exacerbating the greenhouse effect to the point that it became a runaway process, and solar ultraviolet radiation destroyed most of the water molecules; in the past Venus had 100 times more water than it does today.

The runaway greenhouse effect coupled with the warming Sun means that today temperatures on Venus reach 450C and the atmosphere crams in 400 million trillion kilograms of gaseous material, with 96.5 per cent being carbon dioxide laced with clouds of sulphur dioxide.

Compare that to Earth, where only 0.04 per cent of the atmosphere's volume is carbon dioxide. Venus is a tortured, hellish planet that has taken global warming to the extreme, and suffered for it.



› *A false-colour, simulated image of the surface of Venus, based on radar images made by NASA's Magellan spacecraft. Gula Mons, a 3km high volcano, can be seen on the left*

HOW TO OBSERVE

HOW	naked eye
BRIGHTNESS	max magnitude -4.7
WHEN	for most of the year
BEST SEEN	after sunset or before sunrise

Earth

THE THIRD ROCK FROM THE SUN IS THE NOT-TOO-HOT, NOT-TOO-COLD 'GOLDILOCKS' PLANET THAT WE CALL HOME

The largest of the four terrestrial planets, Earth, with its crashing oceans, crustal conveyor belt and protective atmosphere, is the only planet – that we know of – that accommodates life. Earth sits in the so-called 'goldilocks' habitable zone, which means that its distance from the Sun (an average 149.6 million kilometres) allows the water without which life could not survive to run freely on the surface.

THE GREENHOUSE EFFECT

A tiny fraction of carbon dioxide in the atmosphere, a so-called greenhouse gas, traps heat that would normally be re-emitted back into space, keeping the planet wrapped up in its warm blanket. We call this the greenhouse effect. Without it, Earth's average temperature would be -13C.

NATURAL GLOBAL WARMING

Earth is the only planet in the Solar System to experience plate tectonics, the process by which earthquakes and volcanoes occur. Carbon dioxide is released into the atmosphere by volcanoes and then removed in the form of acid rain that causes weathering on silicate rocks. This produces calcium, bicarbonate and silica which run off into rivers and oceans, eventually becoming incorporated into the shells of sea-dwelling organisms as calcium carbonate. When these organisms die, they sink to the ocean floor, where the carbon is incorporated back into the Earth's crust. This cycle is known as the carbon-silicate cycle, and is how natural global warming is regulated.

EFFECTS OF MANKIND

Human activity, such as the burning of fossil fuels and the destruction of forests, is exacerbating global warming beyond its natural levels. A significant increase in carbon dioxide traps more heat within the atmosphere, causing ice sheets to retreat and ice caps to melt, which in turn leads to sea-levels rising.

By studying planets such as Venus we can see how the greenhouse effect works in different circumstances and therefore better understand what is happening to our planet.

DID YOU KNOW... Once upon a time it was thought that Earth was the centre of the Universe, something that Copernicus and Galileo helped disprove.

FACT FILE

CLASSIFICATION	rock planet
ATMOSPHERE	78% nitrogen, 21% oxygen, less than 1% argon, carbon dioxide, water vapour
DIAMETER	12,756km
DISTANCE FROM SUN	149.6 million km
LENGTH OF DAY	23.93 hours
SURFACE TEMPERATURE	15C
NUMBER OF MOONS	one

The Moon

HUMANS HAVE LOOKED UP AT THE SHINING SILVERY DISC OF THE MOON FOR TIME IMMEMORIAL, BUT IT IS ONLY IN THE LAST 50 YEARS THAT WE'VE REALLY COME TO KNOW EARTH'S NEAREST NEIGHBOUR

THE EFFECTS OF THE MOON ON THE EARTH

Were it not for our Moon, Earth might be a very different place. A cataclysmic impact between a Mars-sized object with a nearly formed Earth caused the Moon to coalesce from the debris. The collision is thought to have given Earth its 23.5 degree list, with the Moon stabilising this tilt, giving us our seasons and a range of climatically different zones. The Moon also gives us tides, the twice-daily ebb and flow of the oceans that once provided a vital inter-tidal habitat for life to take that step out of the water and on to land.

FACT FILE

CLASSIFICATION	moon
COMPOSITION	calcium-rich, granite-like rock
DIAMETER	3,476km / 0.27 the size of Earth
DISTANCE FROM EARTH	384,400km
LENGTH OF DAY	27.32 Earth days
SURFACE TEMPERATURE	-150C to 120C

EXPLORATION

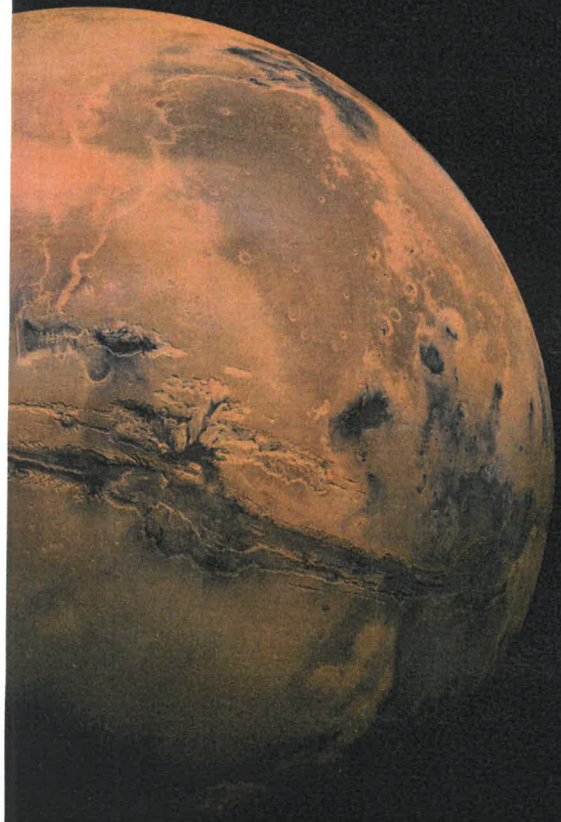
Long thought to be a bone-dry orb, a thin veneer of water was discovered on the Moon's surface in 2009. It is formed when particles from the solar wind, which contains protons, or positively charged hydrogen atoms, collide with oxygen molecules in the lunar soil. Further confirmation came from the 2009 Lunar Crater Observation and Sensing Satellite (LCROSS) mission, which plunged a probe into a permanently shadowed crater at the lunar south pole, throwing up water vapour in the debris.

Methane, ammonia and hydrogen were also seen in the ejecta, along with traces of sodium, silver and mercury – all vital resources for any future manned outpost that would need to mine these raw materials for fuel production, construction and, in the case of water, consumption.

It was 1972 that man last stepped foot on the Moon. How long will it be before we return?

DID YOU KNOW... There are two missions currently doing research in lunar orbit – NASA's Lunar Reconnaissance Orbiter (LRO) and the twin GRAIL spacecraft designed to map the lunar gravity field and learn about the Moon's internal structure.

> Harrison Schmitt, the lunar module pilot on the last mission to the Moon, Apollo 17, stands next to a huge boulder thrown up by an ancient impact. The lunar rover can be seen in the foreground



Mars

THIS RUST-RED PLANET, HOME TO THE SOLAR SYSTEM'S LARGEST MOUNTAIN AND DEEPEST CANYON, MAY ONCE HAVE BEEN WET LIKE EARTH

With its crimson-stained surface and battle-scarred canyons and trenches, the fourth planet from the Sun lives up to its namesake, the Roman god of war. Smaller than Earth yet larger than Mercury, it is hard to believe that Mars was anything like our planet in its early days. Instead, from pole to pole and across its 6,749km diameter, Mars is a cold, rocky and incredibly barren world.

DRY PLANET

Water vapour still exists in Mars's atmosphere and in subsurface deposits of ice stretching from the poles to the mid-latitudes. But the air pressure is such that even if the temperature was warm enough for ice or frost to melt into liquid, it would boil away into the atmosphere.

However, there's evidence of rivers, oceans and glaciers in the past. So where did all the water go? As Mars's core cooled and solidified, the core ceased spinning and its global magnetic field shut off, clearing a path for the solar wind to come in and shear off the top of the atmosphere. Mars's lower gravity means it struggles to keep hold of lighter elements and many water molecules were lost to space. The rest could still be on Mars, but hidden underground in ice deposits or locked up in carbonate rocks.

LIFE ON MARS

In 1996, NASA researchers uncovered evidence of life on Mars in the form of microbial fossils buried deep inside a rock that originated on the red planet 16 million years ago, and fell to Earth 13,000 years ago.

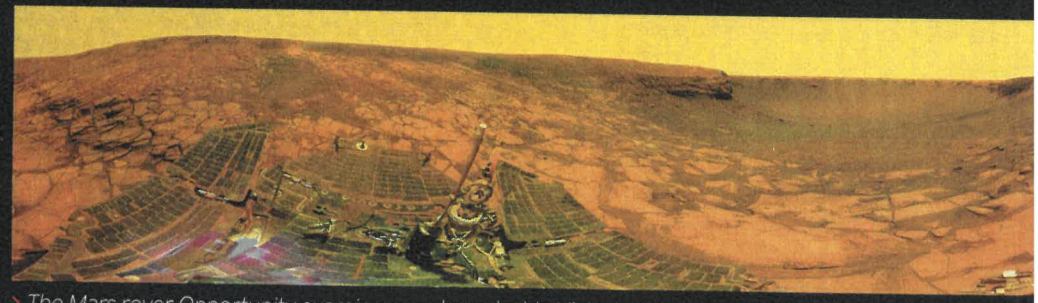
HOW TO OBSERVE

HOW naked eye

BRIGHTNESS magnitude -1.5

WHEN for most of the year

BEST SEEN four or five months either side of opposition



› *The Mars rover Opportunity examines an alcove inside Victoria Crater, nicknamed Duck Bay*

However, scientific opinion, rightly or wrongly, has since questioned the theory that the microscopic structures are Martian fossils.

A similar controversy came during the Viking missions to Mars in the Seventies. Both Viking landers carried experiments to test for primitive life, one of which involved a sample of Martian soil being treated with a vitamin-rich nutrient laced with radioactive carbon-14.

The thinking was that any Martian microbes present in the soil would ingest the nutrient and subsequently 'breathe out' the carbon-14 that would be detected in the air above the sample. Surprisingly this is what was found, but other experiments provided negative results, and so the positive finding was dismissed.

Meanwhile, since 1997, three robotic rovers – Sojourner, Spirit and Opportunity – have landed on Mars to study past and present conditions on the planet. Opportunity still explores the Martian landscape today and will soon be joined by Curiosity, which blasted off for the red planet in late November 2011 and will reach Mars in August 2012.

DID YOU KNOW... The large groove visible on the surface of Mars is Valles Marineris, a canyon system that is 4,000km long, 20km wide and 7km deep.

FACT FILE

CLASSIFICATION rock planet

ATMOSPHERE 95.32% carbon dioxide, 2.7% nitrogen, 1.6% argon, 0.13% oxygen, 0.08% carbon monoxide, minor traces of water, nitrogen oxide, neon, krypton, xenon

DIAMETER 6,792km / 0.53 the size of Earth

DISTANCE FROM SUN 227.9 million km

LENGTH OF DAY 24.62 hours

SURFACE TEMPERATURE -125C to 25C

NUMBER OF MOONS two

› *A view of Gale crater, the destination of NASA's Curiosity rover*

Asteroids and meteorites

BETWEEN MARS AND JUPITER LIES THE ASTEROID BELT, A REGION OF RUBBLE THAT STRETCHES RIGHT AROUND THE SUN. THEY ARE LEFTOVER CHUNKS OF ROCK FROM THE FORMATION OF THE SOLAR SYSTEM, THE BITS THAT DIDN'T MAKE IT INTO THE PLANETS

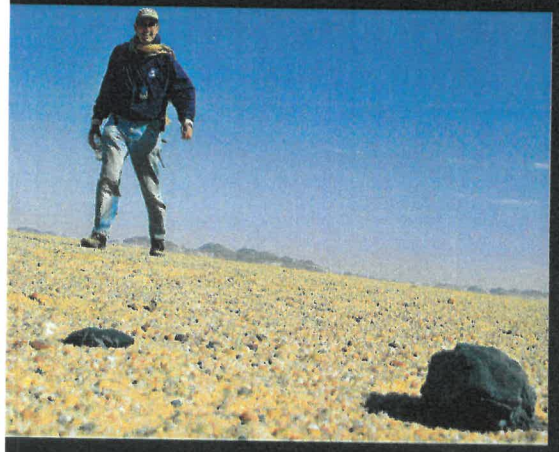
CERES

The largest of the asteroids, Ceres is 972km wide and makes up a third of the entire mass of the asteroid belt. Its large size means that it is actually classed as a dwarf planet. Its low density (2.08 grams per cubic centimetre) reveals that it is not entirely rocky, and that at least a quarter of Ceres is made from a layer of water-ice, 100km deep.

To date Ceres has never been visited by a space probe, and as such remains a bit of a mystery. In 2015 we will get our first close-up view when NASA's Dawn spacecraft enters orbit around it.

OTHER ASTEROIDS IN THE BELT

The rest of the Asteroid Belt's denizens range from a few hundred kilometres down to the size of a dust grain. The mass of all the asteroids together is no more than 4 per cent of the mass of the Moon – not nearly enough to make even a small planet. Instead of the once popular belief that the Asteroid Belt was made from a planet that was ripped apart, we now know that the inverse is true – that these boulders simply didn't make it into larger worlds.



› *Meteorites found on Earth are often worth a lot of money*

ASTEROIDS ACROSS THE SOLAR SYSTEM

While the majority of asteroids safely orbit the Sun in the Asteroid Belt, some end up scattered across the Solar System, often because of collisions with other Asteroids or the gravity of Jupiter throwing them off course. Mars's moons Phobos and Deimos might both be captured asteroids.

A number of asteroids cross Earth's orbit, and it is these that are potentially hazardous to life on Earth. Even a 10km asteroid slamming into the Earth could create a global cataclysm. Fortunately governments and space agencies around the world survey asteroids passing close to Earth to pinpoint any that may be dangerous.

METEORS AND METEORITES

Rocks do fall from space all the time, but fortunately they are too small to do any harm. Many burn up in the atmosphere, which we see as the streaks of light of shooting stars (also known as meteors). Occasionally these rocks may reach the surface of the Earth – these are called meteorites. More than 38,000 meteorites have been found, often as a result of searches in deserts around the world, or in the Antarctic where the black rocks stand out against the snow.

Meteorites have been found hailing not just from the Asteroid Belt, but also from the Moon and Mars. In these cases asteroid or comet impacts on Mars and the Moon have blasted rocks into space which over time have made their way to Earth. Meteorites found on Earth are often worth large amounts of money, with Mars asteroids being the rarest and consequently the most sought after.

DID YOU KNOW... There have been no reported fatalities from meteorite hits, although a dog was reputedly struck and killed in Egypt in 1911.

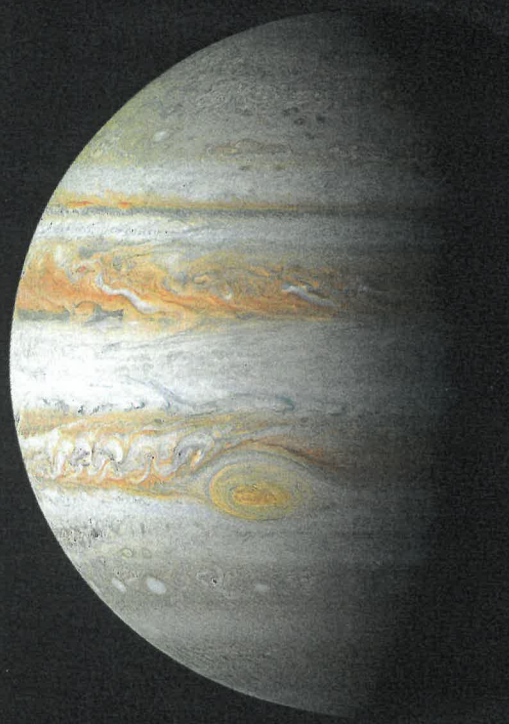
CERES FACT FILE

CLASSIFICATION	asteroid
ATMOSPHERE	none
DIAMETER	972km
DISTANCE FROM SUN	414 million km
SURFACE TEMPERATURE	-100C

› *The bottom of the second-largest asteroid, 530km Vesta, reveals a hidden mystery, a circular feature that may have been caused by an impact, or possibly by some form of internal geological process*

Jupiter

WITH ITS CHARACTERISTIC RED SPOT AND VIVID, SWIRLING BANDS, THE KING OF THE PLANETS AND ITS 64 MOONS HOLDS THE KEY TO PLANET FORMATION, BOTH IN THIS SOLAR SYSTEM AND BEYOND



HOW TO OBSERVE

HOW naked eye

BRIGHTNESS max magnitude -2.9

WHEN visible for approx 10 months each year

BEST SEEN at opposition, every 13 months

Jupiter is essentially a gigantic gas ball. It is the most closely observed of the so-called 'gas giants', which include Saturn, Uranus and Neptune.

SPOTS AND STRIPES

The largest planet in our Solar System, Jupiter is most famous for its Great Red Spot (GRS), a storm that has been spinning for hundreds of years at a rate of about six Earth days per revolution. Capable of consuming Earth two to three times over, it is periodically joined by Red Spot Junior and the baby red spot; on one occasion recorded by the Hubble Space Telescope in July 2008, the GRS swallowed the baby red spot whole, spitting a deformed version of the smaller spot out the other side a few days later.

Jupiter's visible 'surface' is organised into a dozen distinct stripes. The dark bands are known as belts and the light bands as zones, corresponding to sites of descending and upwelling air, respectively. They are bounded by strong winds known as jets that reach speeds of up to 600kmph.

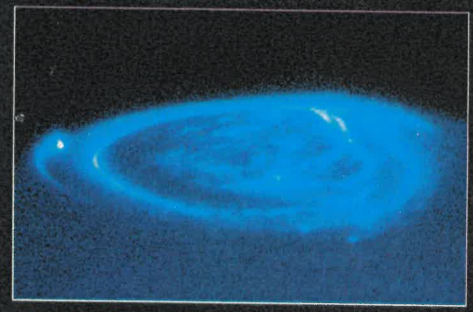
The light colour of the zones is attributed to a higher concentration of ammonia ice clouds, while the belts present thinner, lower altitude clouds. The stripes are often pockmarked with distinct white clouds, the sites of storms that even come with lightning.

MAGNETIC CHARACTER

Jupiter has a magnetic field 14 times the strength of Earth's, resulting in charged particles being accelerated to nearly the speed of light in Jupiter's magnetosphere, which is rooted in electric currents that are likely generated in the planet's rapidly spinning metallic hydrogen interior.

THE GALILEAN SATELLITES

The planet has four large moons known as the Galilean satellites. They are essentially worlds in their own right and, like many siblings, have a diverse range of personalities. Innermost Io is constantly being resurfaced by eruptions of lava, while outermost Callisto's ancient surface is the most cratered body in the entire Solar System.



› *Aurora, Jupiter-style, seen here in ultraviolet light*

Meanwhile, Europa holds promise of an ocean beneath its frozen surface, kept warm by tidal heating from Jupiter that contorts the moon's icy shell every moment of the day. Between Europa and Callisto is rock-ice Ganymede, the largest moon in the Solar System. Ganymede is shaped by tectonic forces; great lesions of light terrain likely caused by upwelling ice cutting through darker, more heavily cratered terrain.

The Galilean satellites may be the leaders of the pack, but they have at least 60 siblings – all less than 250km in diameter and the majority less than 5km wide – often found orbiting in an opposite (retrograde) direction to Jupiter's spin. While some of Jupiter's regular satellites are thought to be leftovers from the planet-building phase, the outer, irregular denizens were likely snatched from their orbits as passing asteroids.

DID YOU KNOW... The Galilean satellites are named after Galileo Galilei, who first saw them through a telescope between December 1609 and January 1610.

The Jovian system is often likened to a mini Solar System and can perhaps give us the most insight into the fundamental processes and conditions that governed the formation of not just our Solar System, but of new planetary systems being found around other stars, too.

› *Volcanic plumes erupting from Io, as recorded by the New Horizons spacecraft in February 2007. Europa is visible in the foreground*

FACT FILE

CLASSIFICATION	gas planet
ATMOSPHERE	89.8% hydrogen, 10.2% helium, less than 1% methane, ammonia, ethane, water
DIAMETER	142,984km / 11.2 times the size of Earth
DISTANCE FROM SUN	778.4 million km
LENGTH OF DAY	9.93 hours
SURFACE TEMPERATURE	-110C
NUMBER OF MOONS	64

› The Cassini spacecraft captured this view of Saturn almost a month after the planet's 2009 equinox

Saturn

BEAUTIFUL BEYOND BELIEF THROUGH THE TELESCOPE EYEPIECE, AND INCREDIBLE WHEN VIEWED UP CLOSE BY THE CASSINI SPACECRAFT, SATURN IS A TRUE SOLAR SYSTEM STUNNER

With its majestic system of rings, Saturn is a world of gas, second in size only to Jupiter and with almost as many moons – 62 to Jupiter's 64. Its rings, which are only a dozen or so metres thick, yet broad enough that they would stretch from Earth to the Moon, are composed of tightly packed boulder-sized ice and dust particles most probably created when a small icy moon or comet got too close to Saturn and was ripped to shreds by its imposing gravity.

THE EQUINOX

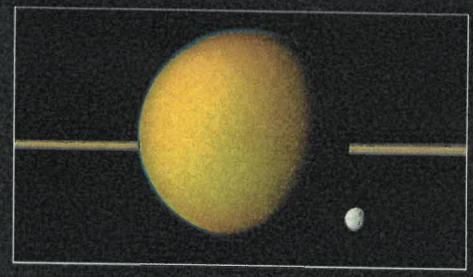
Every 15 years – half a Saturnian year – Saturn's rings are plunged into shadow as the 26.7-degree tilt of the planet brings it level with the plane of the Solar System. In a moment called equinox, the Sun is directly above Saturn's equator, illuminating only the edge of the glorious rings and giving the illusion that the rings have almost disappeared.

During equinox, the tiny moons of Saturn and any structures in the ring that rise above the plane, catch the sunlight and cast their dark shadows on to the golden-hued globe of the ringed planet.

During the last equinox in August 2009, new structures and clumps of material were spotted in Saturn's ring system by NASA's Cassini spacecraft.

FACT FILE

CLASSIFICATION	gas planet
ATMOSPHERE	97% hydrogen, 3% helium, traces of methane, ammonia, water
DIAMETER	120,536km / 9.45 the size of Earth
DISTANCE FROM SUN	1.43 billion km
LENGTH OF DAY	10.67 hours
SURFACE TEMPERATURE	-191C to -130C
NUMBER OF MOONS	62



› Saturn's moons Titan and icy Tethys pose in front of its rings, giving the illusion that Titan has rings

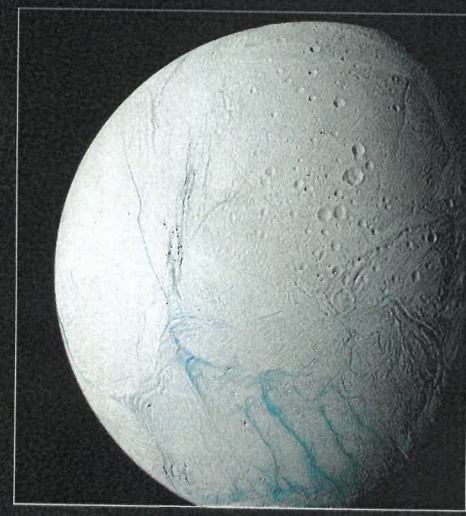
SATURN'S MOONS

Owing to the presence of liquids, including water, Saturn's moons Enceladus and Titan are among the best places to look for some form of life in the Solar System beyond Earth.

Saturn's largest satellite, Titan, is dominated by methane. Temperatures here drop as low as -179C, turning water-ice as hard as rock. But methane, ethane and other hydrocarbons (organic compounds consisting entirely of hydrogen and carbon atoms) flow as liquid, in rivers, lakes and seas.

DID YOU KNOW... Saturn has seven rings in total, named with letters from A to G in order of their discovery.

None of this is to say that Saturn's other moons are dull. Mimas sports a giant crater called Herschel that makes it look reminiscent of the Death Star in *Star Wars*. Iapetus has a yin-yang appearance, one hemisphere a brilliant icy white, the other as dark as coal while a massive equatorial ridge of mountains wraps itself around the moon. Then there is Hyperion, which takes on the appearance of a shattered pumice stone, and Phoebe, a dark and battered relic of the Kuiper Belt that wandered too far in-system and became caught in Saturn's gravity web.



› Geysers erupt from the so-called 'tiger stripes' seen in the southern hemisphere of icy Enceladus

HOW TO OBSERVE

HOW	naked eye
BRIGHTNESS	max magnitude -0.3
WHEN	visible for approx 10 months each year
BEST SEEN	two weeks after its annual opposition when the rings are face on to Earth

Uranus

COLD AND DISTANT, THE BLUE-GREEN ICE GIANT URANUS ORBITS THE SUN TIPPED OVER ON TO ITS SIDE

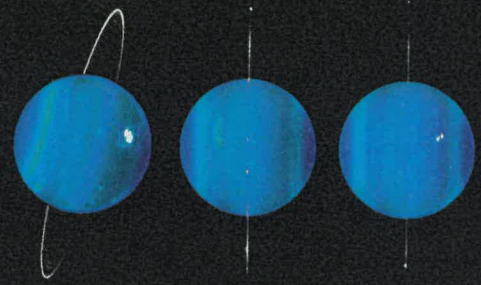
Uranus is one of the gas planets that's often referred to as an 'ice giant' owing to its hydrogen-dominated atmosphere that, at average temperatures of -214C, is mostly ice. Another notable aspect of Uranus is that it orbits the Sun tipped over on its side at an angle of 98 degrees, so that its poles are parallel with Earth's equator.

In 2007 Uranus reached its equinox, where the Sun faces the planet's equator, causing an eruption of activity within its atmosphere. Uranus' tilt means that for half of its 84-year orbit, one half of the planet – its northern pole or its southern pole – is continually in sunlight and the equinox marks the change between the two. The shift in seasons causes different heating of the atmosphere, forcing new weather systems to take shape.

DID YOU KNOW... Uranus is the coldest planet in the Solar System, with an average cloud top temperature of -214C

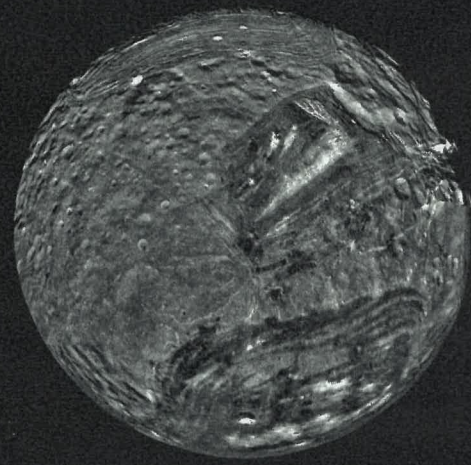
FACT FILE

CLASSIFICATION	gas planet
ATMOSPHERE	hydrogen, helium, methane, ammonia, water, ammonium hydrosulphide, methane
DIAMETER	51,118km / 4 times the size of Earth
DISTANCE FROM SUN	2.87 billion km
LENGTH OF DAY	17.24 hours
SURFACE TEMPERATURE	-214 to -205C
NUMBER OF MOONS	27



AUGUST 15, 2005 AUGUST 8, 2007 AUGUST 9, 2007

> The 10m Keck II telescope imaged Uranus during the run-up to the planet's equinox in 2007, where Uranus' rings appeared edge-on. Also noticeable are numerous bright storms, including a particularly large one seen in 2005



> Uranus's mystifying moon Miranda has a patchwork surface full of giant cliffs, jagged mountains, V-shaped chevrons, craters, scarps and valleys

URANUS'S RINGS AND MOONS

Like all the giant planets, Uranus has a system of rings, as well as 27 attendant moons. Perhaps of most interest are the five largest: Miranda, Ariel, Umbriel, Titania and Oberon. Miranda boasts bizarre, chaotic terrain, a result of it being partially melted and refrozen at different times.

Some of the moons may contain oceans deep beneath their surfaces, and certainly all display evidence of a warmer past: Ariel, for instance, has huge caverns that look as though they could have been carved by a liquid rich in antifreeze ammonia and flowing from ice volcanoes.

HOW TO OBSERVE

HOW	telescope
BRIGHTNESS	max magnitude +5.7
WHEN	visible for approx 10 months each year
BEST SEEN	at opposition every 12 months

› *A Great Dark Spot – a storm similar to Jupiter's Great Red Spot – seen in Neptune's atmosphere*

Neptune

A VIVID AZURE GAS-ICE GIANT THAT STANDS SENTINEL AT THE EDGE OF OUR SOLAR SYSTEM, NEPTUNE IS A WORLD OF WILD WEATHER, 40-YEAR-LONG SEASONS AND A GEOLOGICALLY ACTIVE MOON

Despite being the furthest planet from the Sun, Neptune has a surprisingly active weather system. Dynamic storms rage to speeds in excess of 2,000kmph – the fastest winds seen in the Solar System. With an axial tilt not too different from the Earth's, Neptune also experiences seasons. However, given the greater distance from the Sun, Neptune's seasons reign for 40 years.

NEPTUNE'S ATMOSPHERE

Although the upper reaches of Neptune's atmosphere are a frigid -220C, deeper inside the hydrogen- and helium-dominated envelope the temperature rises steadily. The atmosphere is thought to contain a solid core of iron, nickel and silicate material, wrapped in a mantle of water, ammonia and methane ices.

FACT FILE

CLASSIFICATION	gas planet
ATMOSPHERE	80% hydrogen, 19% helium, 1% methane
DIAMETER	49,532km / 3.88 times the size of Earth
DISTANCE FROM SUN	4.5 million km
LENGTH OF DAY	16.11 hours
SURFACE TEMPERATURE	-234C
NUMBER OF MOONS	13

Unusually, Neptune radiates 2.6 times the energy it receives from the Sun, suggesting it has an internal heat source. Theories include radioactive heating within the planet's core, or a conversion of methane under high pressure into hydrogen or even diamond, providing a source of energy.

TRITON

Neptune has 13 moons, the largest of which is Triton. Triton is Neptune's only spherical moon, and the only large moon in the Solar System with a retrograde orbit (rotating in the opposite direction to its planet). It is also one of only three Solar System objects, alongside Earth and Saturn's moon Titan, known to have a nitrogen-dominated atmosphere. Its frigid -234C surface is one of the coldest places in the Solar System, meaning that its nitrogen component is mostly condensed on its surface as frost.

DID YOU KNOW... Neptune's magnetic pole is mysteriously offset from the geographic poles by 47 degrees and also displaced from its centre.

› *This mosaic of Neptune's largest moon Triton reveals a dynamic surface fresh with activity. The green-coloured region includes Triton's enigmatic 'cantaloupe terrain', named after its likeness to a cantaloupe melon skin*

Triton is geologically active, spewing icy water and ammonia lavas that have carved complex valleys on its surface. Only half of Triton's surface has ever been seen, but with no current planned missions, it is likely to remain an enigma for some decades to come.

HOW TO OBSERVE

HOW	binoculars or telescope
BRIGHTNESS	magnitude 7.8
WHEN	visible for approx 10 months each year
BEST SEEN	at opposition every 12 months

Pluto and the dwarf planets

MOST OF THE DWARF PLANETS LURK IN THE DISTANT KUIPER BELT, A DISC OF ICY BODIES MARKING THE FINAL FRONTIER OF OUR SOLAR SYSTEM

Dwarf planets are halfway houses between full-blown planets and irregularly-shaped minor bodies. They are generally massive enough to be solid (rather than the porous rubble-pile type structures of some comets and asteroids) and spherically shaped, but not massive enough to have cleared their orbits of other large objects.

PLUTO

Pluto falls into the category of dwarf planet, having been reclassified from full planetary status in 2006, following the discovery of a similarly sized icy body in the outer Solar System, named Eris. Pluto had always been an oddity among the planets, its diminutive size lacking the heft of even Mercury and its 248-year orbit so highly elliptical, or oval, that it actually spends 20 years inside the orbit of Neptune.

OTHER DWARF PLANETS

Three other dwarf planets have also been confirmed in the Kuiper Belt – Eris, Haumea and Makemake – but there are a number of other large objects that could also fit the bill, including Quaoar, Sedna and Orcus.

It is believed that a total of nine so-called Kuiper Belt Objects (KBOs) found thus far could be catalogued as dwarf planets, and that there could be anywhere between 50 and 200 in the Kuiper Belt in total. Moons around dwarf planets have also been revealed – Pluto currently has four known moons, Eris, Quaoar and Orcus have one, and Haumea has two. The frequency of moons may indicate past collisions that have chipped chunks off the main body.

Our knowledge of the dwarf planets will soon be receiving a boost. In 2015 NASA's New Horizons spacecraft will soar past Pluto and its moons on a brief but intense fly-by of discovery before heading deeper into the Kuiper Belt.

PLUTO FACT FILE

CLASSIFICATION dwarf planet

ATMOSPHERE 70% rock, 30% ice – nitrogen, carbon dioxide, carbon monoxide, methane

DIAMETER 2,390km / 0.006 the size of Earth

DISTANCE FROM SUN 5.9 billion km

LENGTH OF DAY 6.39 Earth days

SURFACE TEMPERATURE -230C

NUMBER OF MOONS four

LARGEST KNOWN TRANS-NEPTUNIAN OBJECTS (TNOs)

› *Artist's impression of the dwarf planets and other Kuiper Belt objects, along with their moons, in scale with the Earth*

› *When New Horizons speeds past Pluto in July 2015, it may snap a surface that looks something like this, covered in nitrogen, carbon dioxide, carbon monoxide and methane ice*

Comets

IN TIMES PAST COMETS WERE KNOWN AS 'HAIRY STARS' FOR THEIR LONG TAILS AND FUZZY HEADS ('COMAS'). CHUNKS OF ICE AND ROCK, THEY SWOOP IN FROM THE DEPTHS AND FLIRT WITH A CLOSE APPROACH TO THE SUN BEFORE HEADING OFF INTO SPACE AGAIN

Comet tails always point away from the Sun, regardless of the direction of motion of the comet. This is because the tail is 'blown' by the solar wind – a stream of particles emanating from the Sun. The tail is made up of dust, vaporised ice and other gases from the comet's surface.

The most famous comet is Halley's Comet, which returns to Earth every 76 years. Its fame arises from astronomer Edmund Halley's realisation that the comet made periodic returns to our skies. Its last appearance was in 1986, but it has been trumped in terms of pure spectacle by subsequent comets like Hale-Bopp (1997) and Hyakutake (1996) that were easily visible in the night sky from towns and cities.

SHOEMAKER-LEVY 9

The most dramatic comet event of the past few decades occurred in 1994, when comet Shoemaker-Levy 9 wandered too close to Jupiter. Jupiter's powerful gravity ripped the comet into a chain of 21 pieces. During a three-day period in the summer of that year, all 21 fragments ploughed into Jupiter in flashes of light, leaving black scars on the gas giant's surface. It was a reminder of the dangers of comet and asteroid impacts.

INVESTIGATING COMETS

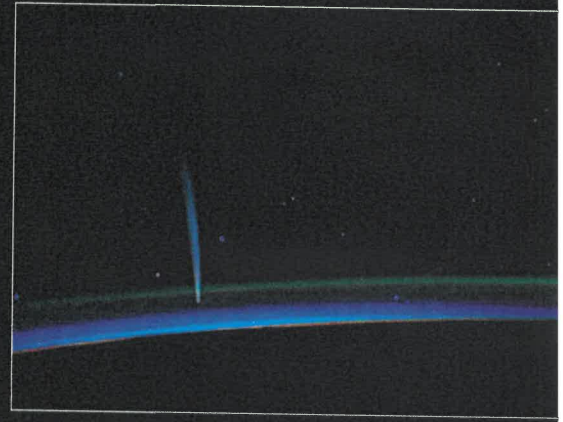
As ever, comets have not escaped the attention of scientists, who have launched several spacecraft to investigate them. The European Space Agency sent the Giotto probe to Comet Halley in 1986, the first time the nucleus of a comet had been photographed. In 2005 NASA's Deep Impact mission hurled a 375kg impactor into the path of 7.5km-wide comet Tempel 1. This created a giant flash, releasing material from inside the comet into space, which the Deep Impact mothership was then able to analyse. Despite the drama of the impact, the crater left behind on the comet was barely noticeable.

› *The great comet of 1995, Hale-Bopp. The thick white tail is the dust tail and the blue tail is the particle, or 'ion', tail*

Comets can be somewhat hit and miss in terms of their appearance in our night sky, and predicting when the next great comet will be is impossible. What is certain is that when a fantastic comet passes us, its tail stretching across the sky, it is a sight not to be missed.

› *The brilliant tail of comet McNaught seen over the telescopes of the European Southern Observatory in Chile*

› *Comet Tempel 1 is struck by a metal probe during NASA's Deep Impact mission*



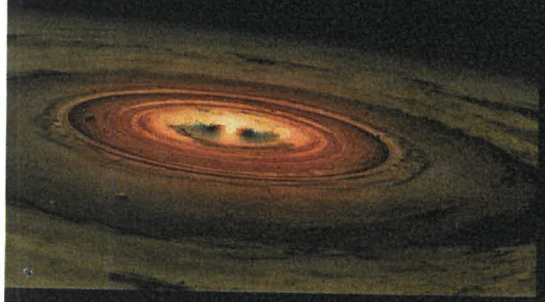
› *Comet Lovejoy seen by astronauts onboard the International Space Station in December 2011*

How the Earth and the Solar System were formed

THE SUN, THE EIGHT PLANETS AND ALL THE DWARF PLANETS, ASTEROIDS AND COMETS CAME FROM WHAT WAS ORIGINALLY JUST A CLOUD OF GAS AND DUST

Our Solar System's story began with a cloud of predominantly hydrogen, but with a good measure of other elements mixed in as gas and dust. The cloud was inert, but a nudge from the shockwaves of a nearby exploding star or a collision with another cloud began to push the gas together.

As densities rose the cloud collapsed under its own gravity, breaking into smaller clumps that became so dense within their cores that temperatures and pressures rose high enough for nuclear fusion to ignite, and the Sun switched on. Elsewhere in the cloud, other stars condensed out of the gas and soon it was alive with starbirth.



An artist's impression of a protoplanetary disc of gas, dust and larger rocky bodies orbiting a young star

THE SOLAR NEBULA

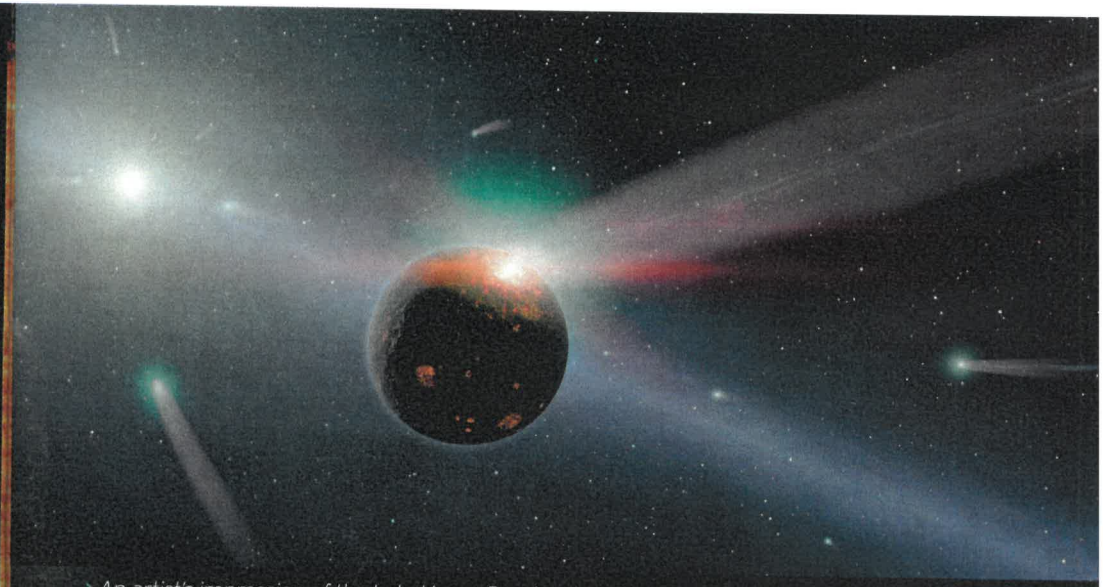
After the Sun formed it was left with a cooling fog of gas and dust rotating in a disc around it – the solar nebula. The inner regions of the disc, where the four terrestrial planets of our Solar System (Mercury, Venus, Earth and Mars) now reside, was the hottest and in these temperatures only certain materials, such as rock, were able to condense into solids. Ammonia, methane, molecular hydrogen and helium were more common in the outer Solar System where conditions were cooler.

The first truly solid bodies began to appear three million years after the formation of the Sun. Through a process known as accretion, dust motes began to stick to chunks of rock and then the chunks of rock began to accumulate into mountain-sized asteroids and then grow even bigger into what we call protoplanets, rocky bodies hundreds of kilometres across. The largest of these bodies were still molten inside, allowing the most dense material within them – iron and nickel – to sink to their cores.

THE ASTEROID BELT

Then came a game of planetary billiards, invoking titanic gravitational collisions between protoplanets, with some being ejected from the Solar System entirely by their neighbours. After the dust had settled a few victors remained – the bulk of the four inner planets, plus a few scattered bodies such as Vesta and Ceres in what became the Asteroid Belt.

This belt marks the 'snowline', beyond which water could condense from the solar nebula and freeze into ice. This is why the moons of the outer planets and the ice giants Uranus and Neptune themselves are replete in so-called 'volatiles' – materials such as water that evaporate easily.



An artist's impression of the Late Heavy Bombardment, where comets were sent hurtling into the inner Solar System to impact with the young planets there

MYSTERIES AND MAYHEM

The formation of bodies in the outer Solar System is still a greater mystery, however. Did the gas giants condense directly from the gaseous elements of the solar nebula, or are they built around cores formed from rocky planetesimals? Evidence from studies suggests that both processes may be at work under differing conditions.

After the Earth had formed, theory has it that it was struck by another protoplanet about the size of Mars known as Theia. The impact utterly destroyed poor old Theia, and took a good chunk out of the Earth as well. Some of this debris rained back down on the planet in a deadly storm of falling rock, but some remained in orbit, forming a belt or ring of debris from which Earth's Moon is thought to have condensed.

THE LATE HEAVY BOMBARDMENT

Around 500 million years after the creation of the Solar System, another bout of impacts was delivered upon the inner worlds by the migrating gas giants jostling for space in the outer Solar System, disrupting the orbits of asteroids and comets and sending them hurtling in-system. This period, known as the Late Heavy Bombardment, has left its scars on the Moon, and comets perturbed by Jupiter's powerful gravity may have brought much needed water from beyond the snowline to Earth and Mars in particular.

Today impacts still occur. In recent years asteroids and comets have plunged into Jupiter's atmosphere, and meteorite falls are a common occurrence on Earth. Next time you see a meteor – or shooting star – streak through the sky, remember that you're watching the burn-up of pieces of rock left over from the construction of the planets.

DID YOU KNOW... The Sun was formed 4.568 billion years ago and is about halfway through its life.

› Do alien civilisations exist elsewhere in the Universe?

The search for life

ARE WE ALONE IN THE UNIVERSE?

The search for extraterrestrial intelligence (SETI) isn't just an esoteric interest among scientists; in some sense it is the ultimate goal of all our attempts to understand the Universe. That is why SETI alone may not be enough to do the job; astronomy, physics, chemistry and biology all have a role to play in understanding how life, particularly intelligent life, began here on Earth and whether it may exist elsewhere.

We turn now to cosmology and the beginning of the Universe, where the formulation of the fundamental constants of nature seem oddly predetermined to be suitable for the transcendence of intelligent life. If gravity were slightly stronger, the Universe would have collapsed in on itself as soon as it began. If the expansion of the Universe were more energetic, it would rip the cosmos apart in no time at all.

If the charge on the electron, the mass of a proton, the speed of light or the nuclear forces that bind together atoms were all just slightly different then stars could not form, nucleosynthesis could not create the elements of the periodic table and life would be impossible. The difference between a flourishing Universe and a dead Universe is a scarily fine line. So our attempt to understand the Universe is driven by a desire to appreciate why it is hospitable to life.

OUR SOLAR SYSTEM

Our search for extraterrestrial life focuses near and far. Mars is a prime target, as is Jupiter's moon Europa, which conceals a deep ocean beneath a thick crust of ice. Saturn's moon Titan possesses some of the organic materials necessary for life but may be too cold to support it, while liquid water also exists on its fellow moon Enceladus. If life does exist elsewhere in the Solar System, it will likely be microbial – gone are the notions of intelligent life on Mars so imaginatively described in the novels of Edgar Rice Burroughs or HG Wells. Our probes to the other planets and moons in the Solar System have shown that Earth is the only habitat where complex life lives.

BEYOND THE SOLAR SYSTEM

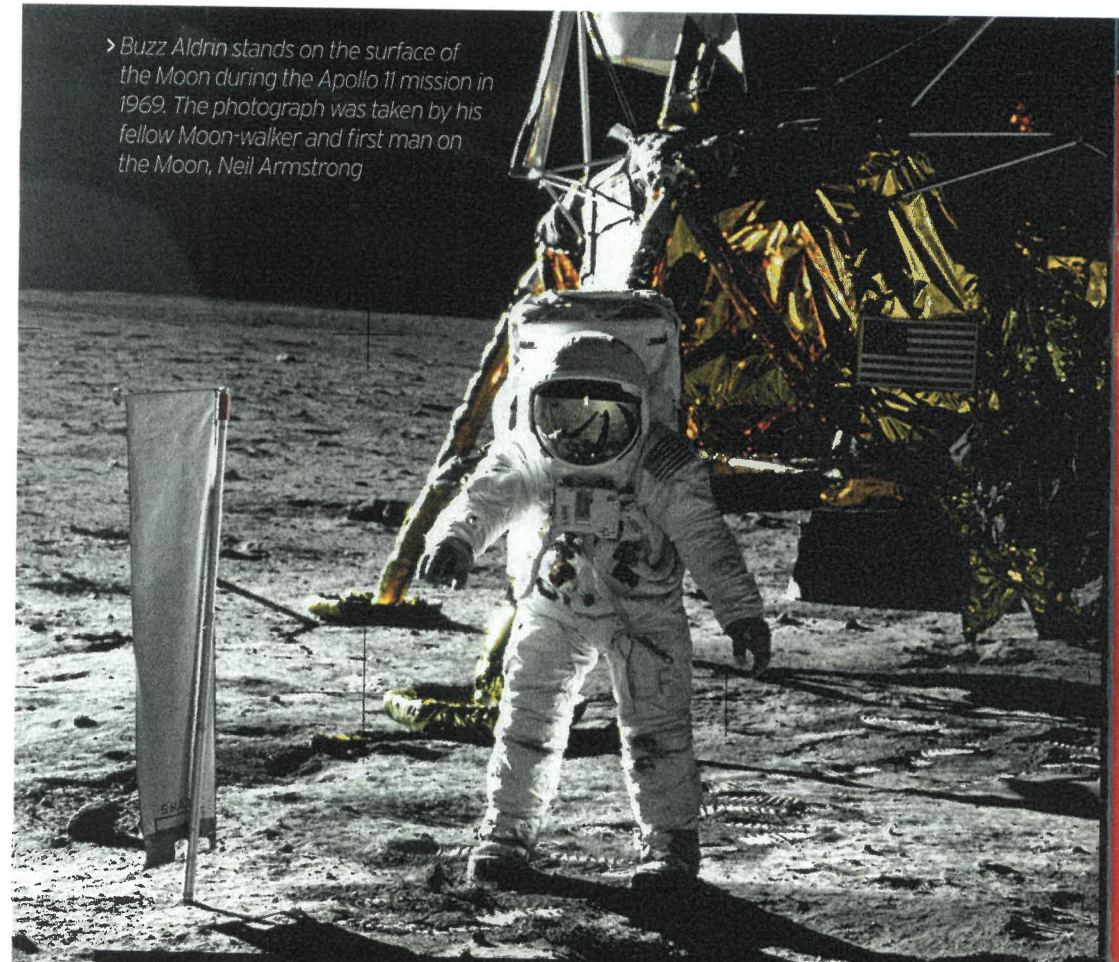
Beyond the Solar System it may be a different matter. Modern SETI has been at work since 1960, when Frank Drake conducted the first search for radio signals from extraterrestrial worlds. Radio waves are thought to be one of the best, if not *the* best, options for interstellar communication, as they can carry large amounts of information and cross vast distances, even passing through interstellar gas and dust. Optical SETI using powerful laser beams is also a possibility. In more than 50 years, however, there has been no evidence of intelligent life out there, but we've barely scratched the surface. Only a thousand or so stars, out of the hundreds of billions in our Galaxy, have been searched in depth. As computer processing power increases, SETI scientists will have the ability to search many more stars using dedicated radio telescopes such as the Allen Telescope Array in California.

A CONTROVERSIAL TOPIC

Critics claim SETI is a waste of money that could be better spent elsewhere. However, in the United States SETI has been entirely privately funded for two decades, while SETI is not funded at all in the UK or Europe. However, the discovery of intelligent alien life could completely change how we view human life and our place in the Universe.

DID YOU KNOW... An online project called SETI@Home allows anyone with a computer and internet connection to help in the search for extra-terrestrial life. Read more in tomorrow's guide to the stars and galaxies.

› Radio telescopes sit patiently waiting for a signal from the stars



› Buzz Aldrin stands on the surface of the Moon during the Apollo 11 mission in 1969. The photograph was taken by his fellow Moon-walker and first man on the Moon, Neil Armstrong

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